8.4 Earth's Layered Structure

Reading Focus

Key Concepts

- What are Earth's layers based on composition?
- What are Earth's layers based on physical properties?
- How did scientists determine Earth's structure and composition?

Vocabulary

- crust
- mantle
- lithosphere
- asthenosphere
- outer core
- inner core
- Moho

Reading Strategy

Sequencing Copy the flowchart. After you read, complete the sequence of layers in Earth's interior.

Earth's Internal Structure

Lithosphere → a. ? → b. ? → Outer core → c. ?

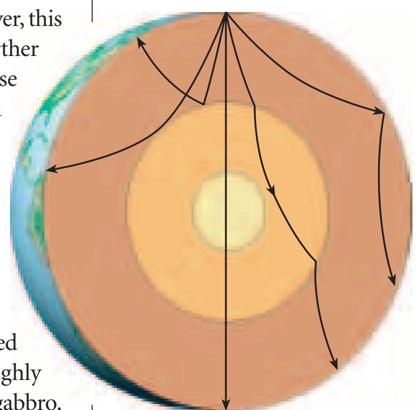
Compared to the planets we see in the night sky, Earth's interior is close by. But we can't reach it. The deepest well has drilled only 12 kilometers into Earth's crust. With such limited access, how do we know what Earth's interior is like? Most knowledge of the interior comes from the study of seismic waves that travel through Earth.

Layers Defined by Composition

If Earth's materials had the same properties throughout, seismic waves would spread through it in straight lines at constant speed. However, this is not the case. Seismic waves reaching seismographs located farther from an earthquake travel at faster average speeds than those recorded at locations closer to the event. This general increase in speed with depth is due to increased pressure, which changes the elastic properties of deeply buried rock. As a result, the paths of seismic waves through Earth are refracted, or bent, as they travel. Figure 14 shows this bending. **Earth's interior consists of three major layers defined by their chemical composition—the crust, mantle, and core.**

Crust The **crust,** the thin, rocky outer layer of Earth, is divided into oceanic and continental crust. The oceanic crust is roughly 7 kilometers thick and composed of the igneous rocks basalt and gabbro. The continental crust is 8–75 kilometers thick, but averages a thickness of 40 kilometers. It consists of many rock types. The average composition of the continental crust is granitic rock called granodiorite. Continental rocks have an average density of about 2.7 g/cm^3 and some are over 4 billion years old. The rocks of the oceanic crust are younger (180 million years or less) and have an average density of about 3.0 g/cm^3.

Figure 14 The arrows show only a few of the many possible paths that seismic waves take through Earth.
Inferring ***What causes the wave paths to change?***



Section 8.4

1 FOCUS

Section Objectives

8.10 **List** the layers of Earth based on composition and physical properties.
8.11 **Describe** the composition of each layer of Earth.
8.12 **Explain** how scientists determined Earth's structure and composition.

Reading Focus

Build Vocabulary L2

LINCS Have students: **L**ist the parts of the vocabulary that they know, such as *core, sphere,* and *litho-*. **I**magine what the interior of Earth might look like and how the terms might fit together. **N**ote a reminding, sound-alike term, such as apple core or atmosphere. **C**onnect the terms, perhaps in a long sentence or as labels on a diagram. **S**elf-test.

Reading Strategy L2

a. asthenosphere
b. lower mantle
c. inner core

2 INSTRUCT

Layers Defined by Composition

Use Visuals L1

Figure 14 Have students look at the model of Earth and seismic waves in the diagram. Ask: **One seismic wave travels straight through the center of Earth. Would this be a P wave or an S wave?** *(P wave)*
Visual

Facts and Figures

Core-Mantle Boundary One of the strangest regions within Earth is the boundary between the rocky mantle and liquid iron outer core. Here, upside-down mountains of rock stick into the flowing ocean of liquid iron, getting eroded and then redeposited in upside-down "ocean" basins at the bottom of the mantle. The Core-Mantle Boundary Region (CMBR) is an important gateway between the core and mantle. Heat flowing out of the core heats the base of the mantle, providing the thermal source of major hot spots like Hawaii. Meanwhile, sinking pieces of cold ocean lithosphere pile up at the bottom of the mantle, cooling off the core and affecting Earth's magnetic field by changing the flow patterns of the outer core's liquid iron.

Answer to . . .

Figure 14 *Seismic waves change direction because as pressure increases with depth, elastic properties of rocks change.*

Layers Defined by Physical Properties

Build Reading Literacy L2

Refer to **p. 502D** in **Chapter 18**, which provides the guidelines for using visualization.

Visualize Have students keep their books closed. Tell them to listen carefully while you read the paragraph about defining the layers of Earth based on physical properties. Ask students to describe how they visualize the interior of Earth. Then, ask students to work in pairs and discuss how they visualized the process.
Visual

Teacher Demo

Floating Crackers L2

Purpose To model for students the characteristics and behavior of the lithosphere and asthenosphere.

Materials shallow baking pan, package of chocolate pudding, 2 cups of milk, several animal crackers

Procedure Review with students the general characteristics and thicknesses of the lithosphere and asthenosphere. You may want to introduce the idea of the lithosphere being broken into smaller pieces called plates. These plates move about on top of the asthenosphere. Then make the pudding and pour it into the shallow baking pan. This will model the asthenosphere. Once the pudding has set, place the animal crackers on top of the asthenosphere to represent the lithosphere.

Expected Outcomes Students should see that the lithospheric plates are relatively thin compared to the asthenosphere. They also can see how the lithosphere "floats" on top of the asthenosphere, without sinking into it. The asthenosphere has a solid consistency yet has some ability to move.
Logical, Visual

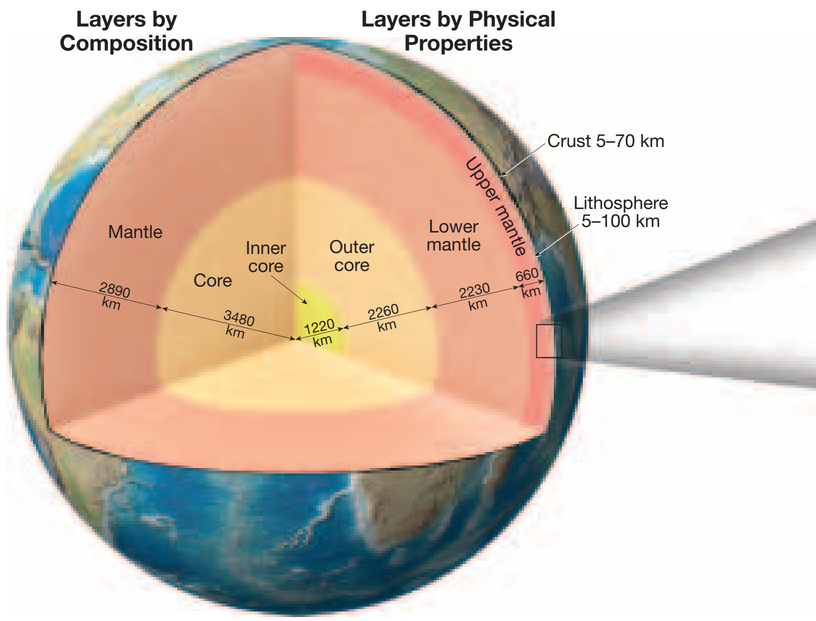


Figure 15 Earth's Layered Structure Based on composition, Earth is made up of the crust, mantle, and core. Based on physical properties, Earth is made up of the lithosphere, asthenosphere, lower mantle, outer core, and inner core. The block diagram shows the relationship between the crust, lithosphere, and asthenosphere. **Inferring** ***Which part of Earth has the highest density? Explain.***

Mantle Over 82 percent of Earth's volume is contained in the **mantle**—a solid, rocky shell that extends to a depth of 2890 kilometers. The boundary between the crust and mantle represents a change in chemical composition. A common rock type in the uppermost mantle is peridotite, which has a density of about 3.4 g/cm^3.

Core The core is a sphere composed mostly of an iron-nickel alloy. At the extreme pressures found in the center of the core, the iron-rich material has an average density of 13 g/cm^3 (13 times denser than water).

Layers Defined by Physical Properties

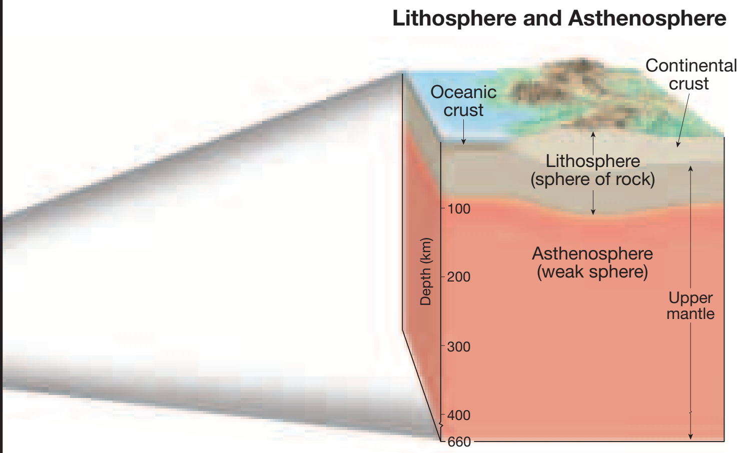
Earth's interior has a gradual increase in temperature, pressure, and density with depth. When a substance is heated, the transfer of energy increases the vibrations of particles. If the temperature exceeds the melting point, the forces between particles are overcome and melting begins.

If temperature were the only factor that determined whether a substance melted, our planet would be a molten ball covered with a thin, solid outer shell. Fortunately, pressure also increases with depth and increases rock strength. Depending on the physical environment (temperature and pressure), a material may behave like a brittle solid, a putty, or a liquid. **Earth can be divided into layers based on physical properties—the lithosphere, the asthenosphere, lower mantle, the outer core, and the inner core.**

Customize for English Language Learners

Imagine that Earth was a ball. If you could cut it in half, you would see that Earth is made up of layers. The deepest layer is a solid core of metal, which is surrounded by a core of liquid metal. The liquid metal spins as Earth rotates. These two parts are thick and extremely hot. The next layer is called the mantle. The mantle is much cooler than the core, but it is still so hot that some of the rock is completely liquid.

A brittle crust of solid rock covers the mantle. All life on Earth exists on the top layer of this crust. Now imagine that you are taking a trip through Earth. Write and illustrate a journal entry for your trip. Share your journal entry with the class.



Lithosphere Earth's outermost layer consists of the crust and uppermost mantle and forms a relatively cool, rigid shell called the **lithosphere**. This layer averages about 100 kilometers in thickness.

Athenosphere Beneath the lithosphere lies a soft, comparatively weak layer known as the **asthenosphere.** Within the asthenosphere, the rocks are close enough to their melting temperatures that they are easily deformed. Thus, the asthenosphere is weak because it is near its melting point, just as hot wax is weaker than cold wax. The lower lithosphere and asthenosphere are both part of the upper mantle.

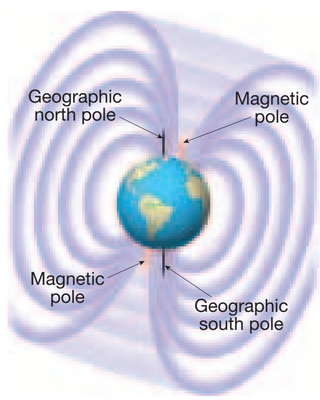
Lower Mantle From a depth of about 660 kilometers down to near the base of the mantle lies a more rigid layer called the lower mantle. Despite their strength, the rocks of the lower mantle are still very hot and capable of gradual flow.

Inner and Outer Core The core, which is composed mostly of an iron-nickel alloy, is divided into two regions with different physical properties. The **outer core** is a liquid layer 2260 kilometers thick. The flow of metallic iron within this zone generates Earth's magnetic field. Just as there is a magnetic field around a bar magnet, an immense magnetic field surrounds Earth, as shown in Figure 16. The poles of the magnetized needle on a compass align themselves with Earth's magnetic field.

The **inner core** is a sphere having a radius of 1220 kilometers. Despite its higher temperatures, the materials in the inner core is compressed into a solid state by the immense pressure.

Reading Checkpoint *Why is the inner core solid?*

Figure 16 Earth's Magnetic Field Movements in Earth's liquid outer core produce the planet's magnetic field. As a result, a compass needle points to one of the magnetic poles.



Build Science Skills L2

Calculating The mantle makes up roughly 82 percent of Earth. The mantle is composed of two different layers, the upper mantle and the lower mantle. The mantle reaches to a depth of approximately 2900 km. **Using the numbers given on Figure 15, what percent of the mantle is upper mantle?** *(660 km/2900 km = 23 percent)* **What percent is lower mantle?** *(2230 km/2900 km = 77 percent)*
Logical

Integrate Language Arts L2

Word Parts Students can remember vocabulary by recognizing word parts in certain words. For example, the Greek suffix *litho-* means "rock, or stone." Ask: **What other word part is a clue to meaning of vocabulary terms such as lithosphere and asthenosphere?** *(–sphere)* **What do you think it means?** *(Sample answer: rounded)*

Facts and Figures

Water in the Mantle When people talk about the water cycle, they usually refer to the cycle of evaporation and precipitation on Earth's surface, but there is another water cycle. Rocks in the oceanic lithosphere can contain trapped water. As the rocks sink into the mantle, heat releases the water. Most of this water comes back up beneath the stratovolcanoes at subduction zones. But some water makes it much deeper, eventually coming back up at mid-ocean ridges or hot-spot volcanoes, like Iceland. It has been estimated that there could be many oceans worth of water within the rock of the mantle. Water weakens rock and makes it flow and melt more easily, so mantle water could affect the vigorousness of mantle convection (and therefore plate tectonics), the melting of rock to make some hot-spot volcanoes, and even the breakup of supercontinents.

Answer to . . .

Figure 15 *The core is densest because it is made up largely of the dense materials iron and nickel.*

Reading Checkpoint *because it is under extreme pressure and is compressed into a solid as a result*

Discovering Earth's Layers

Integrate Physics

L2

Physical and Chemical Properties Have students read the caption for Figure 17. Then ask students for examples of physical and chemical properties. Make a two-column chart on the board and compile a list of physical and chemical properties. *(Examples of physical properties: conductivity, hardness, melting point, density, pressure. Examples of chemical properties: flammability, reactivity.)* Ask: **What physical properties change between the mantle and outer core?** *(hardness, density, pressure, state; outer core is liquid, mantle is solid)*

Build Reading Literacy

L1

Refer to **p. 186D** in **Chapter 7**, which provides guidelines for relating text and visuals.

Relate Text and Visuals Instruct students to look at Figure 17. Refer them to the key and point out that P waves and S waves are different colors in the picture. Ask: **What happens when P waves hit the mantle-core boundary?** *(They bend around the core, or go through the core.)* **What sentences in the text support this observation?** *("It was observed that P waves were bent around the liquid outer core. . . P waves that travel through the core. . . ")* **What happens when S waves meet the boundary?** *(They stop traveling.)* **What sentence in the text supports this?** *("It was further shown that S waves could not travel through the outer core.")*

Discovering Earth's Layers

Recall that seismic waves bend as they travel through Earth and that this information helped scientists to infer the planet's layered structure. **During the twentieth century, studies of the paths of P and S waves through Earth helped scientists identify the boundaries of Earth's layers and determine that the outer core is liquid.**

In 1909, a Croatian seismologist, Andrija Mohorovičić, presented the first evidence of layering within Earth's mantle. By studying seismic records, he found that the velocity of seismic waves increased abruptly about 50 kilometers below eastern Europe. This boundary separates the crust from the underlying mantle and is now known as the Mohorovičić discontinuity. The name of the boundary is usually shortened to **Moho.**

Another boundary had been discovered in 1906 between the mantle and outer core. Seismic waves from even small earthquakes can travel around the world. This is why a seismograph in Antarctica can record earthquakes in California or Italy. However, it was observed that P waves were bent around the liquid outer core beyond about 100 degrees away from an earthquake. The outer core also causes P waves that travel through the core to arrive several minutes later than expected. This region, where bent P waves arrive, is sometimes called the shadow zone.

The bent wave paths can be explained if the core is composed of material that is different from the overlying mantle. The P waves bend around the core in a way similar to sound waves being bent around the corner of a building. For example, you can hear people talking from around the side of a building even if you cannot see them. In this way, rather than actually stopping the P waves in the shadow zone, the outer core bends them, as you can see modeled in Figure 17. It was further shown that S waves could not travel through the outer core. Therefore, geologists concluded that this layer is liquid.

Reading Checkpoint *What is the Moho?*

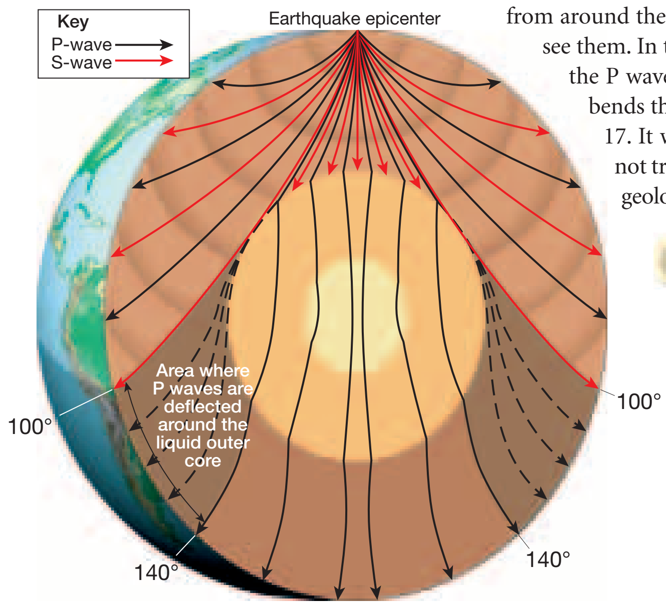


Figure 17 Earth's Interior Showing P and S Wave Paths The change in physical properties at the mantle-core boundary causes the wave paths to bend sharply.

Facts and Figures

Mineral Physics Scientists can interpret seismic properties of particular rock types by performing high-pressure experiments. Small samples of rock and metal are squeezed and heated to the same conditions found in Earth's deep interior, and the speed of P and S waves traveling through the samples are measured. One of the most effective ways of doing this is to put a tiny rock sample between two large diamonds with flat surfaces. Diamond is the hardest naturally occurring substance, and can usually withstand the pressures (though they do sometimes shatter). Diamonds are also transparent, so the rock sample can be heated by a laser shone through the diamond. This is how we know that the single most abundant material within Earth is the rock perovskite, which makes up most of the lower mantle.

Discovering Earth's Composition

To determine the composition of Earth's layers, scientists studied seismic data, rock samples from the crust and mantle, meteorites, and high-pressure experiments on Earth materials. Scientists obtain data on the seismic properties of rocks by performing high-pressure experiments. Small samples of rock and metal are squeezed and heated to the same conditions found in Earth's deep interior. Scientists then measure the speeds of P and S waves through the samples.

Seismic data and rock samples from drilling indicate that the continental crust is mostly made of low-density granitic rocks. Until the late 1960s, scientists had only seismic evidence they could use to determine the composition of oceanic crust. The development of deep-sea drilling technology made it possible to obtain rock samples from the ocean floor. The crust of the ocean floor has a basaltic composition.

The composition of the rocks of the mantle and core is known from more indirect data. Some of the lava that reaches Earth's surface comes from the partially melted asthenosphere within the mantle. In the laboratory, experiments show that partially melting the rock called peridotite produces a substance that is similar to the lava that erupts during volcanic activity of islands such as Hawaii.

Surprisingly, meteorites that collide with Earth provide evidence of Earth's inner composition. Meteorites are assumed to be composed of the original material from which Earth was formed. Their composition ranges from metallic meteorites made of iron and nickel to stony meteorites composed of dense rock similar to peridotite. Because Earth's crust contains a smaller percentage of iron than do meteorites, geologists believe that the dense iron, and other dense metals, sank toward Earth's center during the planet's formation.

Section 8.4 Assessment

Reviewing Concepts

1. Describe Earth's layers based on composition.
2. List Earth's layers based on physical properties, and their characteristics, in order from Earth's center to the surface.
3. What evidence led scientists to conclude that Earth's outer core is liquid? Explain.

Critical Thinking

4. **Comparing and Contrasting** Compare the physical properties of the asthenosphere and the lithosphere.
5. **Inferring** Why are meteorites considered important clues to the composition of Earth's interior?

Writing in Science

Creative Writing Write a short fictional story about a trip to Earth's core. Make sure the details about the layers of Earth's interior are scientifically accurate.

Discovering Earth's Composition

3 ASSESS

Evaluate Understanding L2

Ask students to draw two cross sections of Earth: one where the layers are defined by composition and one where the layers are defined by physical properties. Have students exchange papers and check each other's work.

Reteach L1

Use Figure 15 to review the layers of Earth.

Writing in Science

Stories will vary but students should include accurate information on the lithosphere, upper mantle, lower mantle, as well as the inner and outer core.

Section 8.4 Assessment

1. Based on composition, Earth is made up of the rocky crust, the mantle (made of rock-forming materials), and the metallic, iron-nickel core.
2. inner core, outer core, lower mantle, asthenosphere, lithosphere (upper mantle)
3. Scientists studied the different paths that P waves and S waves take inside Earth to determine the nature of Earth's core. P waves bent in a pattern indicating the existence of a boundary between the core and the mantle. The fact that S waves did not travel through the outer core indicated that the outer core is liquid.
4. The lithosphere is a cool, rigid shell formed from the crust and upper mantle. On average it is 100 km thick. The asthenosphere is a soft, weak layer that experiences the conditions needed to produce a small amount of melting.
5. Meteorites are thought to be made of the same material from which Earth was formed. Therefore, when they are found, they can give us an indication of the composition of the interior of Earth.

Answer to . . .

Reading Checkpoint: *The Moho is the boundary between the crust and the mantle.*

How the Earth Works

1 FOCUS

Objectives

In this feature, students will
- explain what causes an earthquake.
- describe the possible physical effects of an earthquake.

Reading Focus

Build Vocabulary L2

Key Terms Write the key terms on the board. Ask volunteers to write definitions beside them. Then have the class work together to use the words in sentences that describe the causes and effects of earthquakes.

2 INSTRUCT

Bellringer L1

Ask students what comes to mind when they think of earthquakes. Discuss earthquake experiences they may have had or heard about.
Verbal

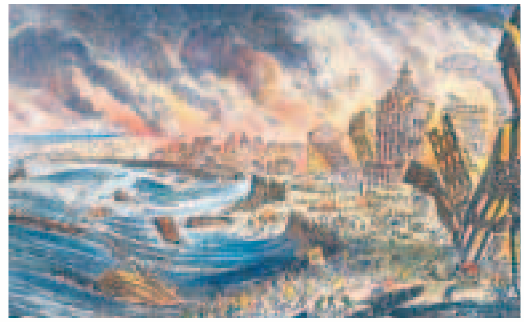
Use Visuals L1

Have students read and examine the photographs on this page and the next. Ask: **What do you suppose people in these regions had to do after the earthquake?** *(They had to find people who were trapped under snow and rubble, rebuild buildings, and fix streets.)*
Visual

How the Earth Works

Effects of Earthquakes

An **earthquake** is a shaking of the ground caused by sudden movements in the Earth's lithosphere. The biggest quakes are set off by the movement of tectonic plates. Some plates slide past one another gently. However, others get stuck, and the forces pushing the plates build up. The stress mounts until the plates suddenly shift their positions and cause the Earth to shake. Most earthquakes last less than one minute. Even so, the effects of an earthquake can be devastating and long-lasting.



TSUNAMI
In 1755, an earthquake in Lisbon, Portugal, caused a tsunami, as illustrated in this painting. A **tsunami** is a huge sea wave that is set off by an undersea earthquake or volcanic eruption. When tsunamis break on shore, they often devastate coastal areas. Tsunamis can race at speeds of about 450 miles per hour and may reach heights of about 100 feet (30.5 m).

LANDSLIDE
In January 2001, an earthquake struck El Salvador. It caused the landslide that left these Salvadoran women homeless. A **landslide** is a sudden drop of a mass of land down a mountainside or hillside. Emergency relief workers from around the world often rush to the site of an earthquake disaster like the one that occurred in El Salvador.

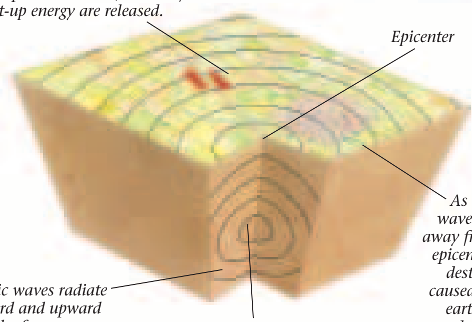
Customize for Inclusion Students

Gifted Ask students to research a historic earthquake, like the one that hit Lisbon in 1755. Have them imagine that they survived it and are writing a story about it for a foreign newspaper. Encourage them to use factual details and fictional interviews in their stories. Before they begin, remind them that the first paragraph should answer these questions: *Who? What? Where? When?* and *Why?*

INFRASTRUCTURE DAMAGE
When an earthquake occurred in Los Angeles in 1994, underground gas and water lines burst, causing fires and floods. Earthquakes often cause tremendous damage to the **infrastructure**—the network of services that supports a community. Infrastructure includes power utilities, water supplies, and transportation and communication facilities.

AVALANCHE
Earthquakes may trigger an **avalanche**—a sudden fall of a mass of ice and snow. In 1970, a severe earthquake off the coast of Peru caused a disastrous slide of snow and rock that killed some 18,000 people in the valley below.

WHEN THE EARTH CRACKS
Most people killed or injured by an earthquake are hit by debris from buildings. Additional damage can be caused by **aftershocks**—tremors that can occur hours, days, or even months after an earthquake. The scene above shows the city of Anchorage, Alaska, after a major earthquake. Extensive ground tremors caused the street to break up as the soil below it collapsed. Buildings and cars were dropped more than 10 feet (3 m) below street level.



SEISMIC WAVES
As tectonic forces build, rock beneath the surface bends until it finally breaks. The tectonic plates suddenly move, causing **seismic waves,** or vibrations, to travel through the ground. The waves radiate outward from an underground area called the focus, or hypocenter. Damage is usually greatest near the **epicenter,** the point on the surface directly above the focus.

ASSESSMENT

1. **Key Terms** Define **(a)** earthquake, **(b)** tsunami, **(c)** landslide, **(d)** infrastructure, **(e)** avalanche, **(f)** aftershock, **(g)** seismic wave, **(h)** epicenter.
2. **Physical Processes** What physical processes cause an earthquake?
3. **Environmental Change** How can an earthquake cause changes to the physical characteristics of a place?
4. **Natural Hazards** **(a)** How can an earthquake change the human characteristics of a place? **(b)** How does the international community respond to a devastating earthquake?
5. **Critical Thinking** **Solving Problems** What can a community do to reduce the amount of earthquake damage that might occur in the future?

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3 ASSESS

Evaluate Understanding L2

Work with students to model how an earthquake happens. Encourage them to build models using everyday classroom materials, such as books for tectonic plates and paper strips for seismic waves.

Reteach L1

Group students in groups of four or five. Have each group create an earthquake safety pamphlet. Tell students to find out the recommended ways to protect themselves during an earthquake. Have them create a pamphlet that explains and illustrates safety instructions. Each group should have researchers, an editor to compile the instructions, and an illustrator to create the pictures. Post the completed pamphlets on a bulletin board.

Assessment

1. **(a)** a shaking of the ground caused by sudden movements in Earth's crust; **(b)** a huge sea wave that is set off by an undersea earthquake or volcanic eruption; **(c)** a sudden drop of a mass of land down a mountainside or hillside; **(d)** the network of services that supports a community; **(e)** a sudden fall of a mass of ice and snow; **(f)** tremors that can occur days, or even months, after an earthquake; **(g)** vibrations that travel through the ground; **(h)** the point on the surface directly above the focus
2. sudden movements in Earth's crust
3. Earthquakes can change the level of the land, cause fires and floods, and cover areas with snow and ice.
4. **(a)** Sample answer: Damage from an earthquake can destroy buildings and make a place uninhabitable; **(b)** Emergency relief workers from around the world may arrive to help with rescue and cleanup efforts. People around the world may donate money to help victims survive until they rebuild their lives.
5. Sample answers: Design buildings to withstand the shock of an earth quake. Build villages, towns, and cities far from fault lines.